Design and Analysis of Adaptive Neural Controller for Voltage Source Converter for STATCOM

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***Abstract*—Usually a STATCOM is installed to support power system networks that have a poor power factor and often poor voltage regulation. It is based on a power electronics voltage-source converter. Various PWM techniques make selective harmonic elimination possible, which effectively control the harmonic content of voltage source converters. The distribution systems have to supply unbalanced nonlinear loads transferring oscillations to the DC-side of the converter in a realistic operating condition. Thus, additional harmonics are modulated through the STATCOM at the point of common coupling (PCC). This requires more attention when switching angles are calculated offline using the optimal PWM technique. This paper, therefore, presents the artificial neural network model for defining the switching criterion of the VSC for the STATCOM in order to reduce the total harmonic distortion (THD) of the injected line current at the PCC. The model takes into the account the dc capacitor effect, effects of other possible varying parameters such as voltage unbalance as well as network harmonics. A reference is developed for offline prediction and then implemented with the help of back propagation technique.**

***Index Terms*— STATCOM, voltage source converter, selective harmonic elimination, adaptive neural controller, total harmonic distortion.**

I. Introduction

The Static Synchronous Compensator (STATCOM) has the capability of generating and /or absorbing reactive power at a faster rate [1]. It can control the line voltage at the point of common connection to the electric power network [2, 3]. The 3-phase output voltage produced by the voltage source converter (VSC), which forms the power stage of STATCOM, is nearly in phase with, and coupled to the corresponding AC grid voltage through a relatively small reactance [4-6]. In case of VSC, a capacitor bank is placed into the DC link, which has the capabilities of harmonic filtering and load balancing in addition to reactive power compensation. This leads to the generation of harmonic components superimposed on fundamental voltage component at the AC side of VSC due to the turning on and turning off, of the IGBT switches at frequencies much higher than the supply frequency [7]. Many methods [8-12] such as selective harmonic elimination, variable modulating function based PWM and correcting optimized PWMswitching patterns were implemented to obtain waveform with minimum harmonic content from VSC. The effect and analysis of switching pattern, modulation index variation and load variations on voltage and current harmonics were carried out [13-16] to cancel low order harmonics. But the harmonic output at PCC was not discussed. Therefore, a strategy was proposed [17] for voltage balancing of distinct dc buses in cascaded H- bridge rectifier. The method was used to ensure that the dc bus capacitor voltage converges to the reference value, even when the loads attached to them extracts different power. Both stepped and PWM methods were used to reduce the current and voltage harmonics. In all such methods discussed above, it is observed that the conventional methods can give good control capability over a wide range of operating conditions. But they need a mathematical model of the system to be controlled, which in most cases cannot be obtained easily.

In the above context, this paper presents a VSC based STATCOM using ANN in which voltage regulation is achieved, and the input voltage harmonics are minimized by selective harmonic elimination technique (SHEM) to comply with IEEE Std. 519-1992 [18]. A brief introduction has been provided for the role of VSC for STATCOM applications and various PWM techniques to minimize voltage and current harmonics of VSC. Section II contains the inside view of the STATCOM followed by the introduction of SHEM. In section III the design of neuro controller is explained. Finally, the validation and comparison of results is described in section IV, followed by conclusion in section V.

II. Conventional STATCOM Model

The basic decoupled conventional control scheme of a STATCOM to be considered is shown in Fig. 1. The two PI controllers, PI_v and PI_{DC}, are for regulating the line voltage at the point of common coupling (PCC) and the dc link voltage inside the device. The deviations in the line voltage ÄV and the dc link voltage $ÄV_{dc}$ are passed through these two decoupled PI controllers in order to determine the inverter modulation index m_a and the phase shift á, respectively.

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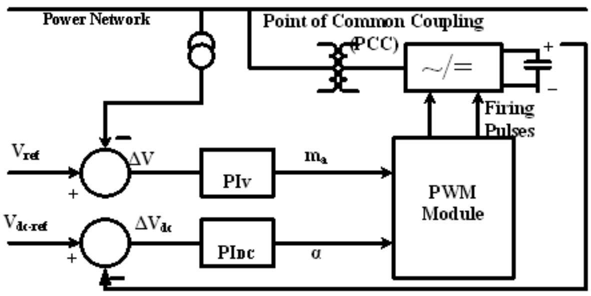

Figure 1. STATCOM: decoupled control scheme

A. Reactive Power Control

Fig. 2 represents a simplified Single phase Y-equivalent model of STATCOM.

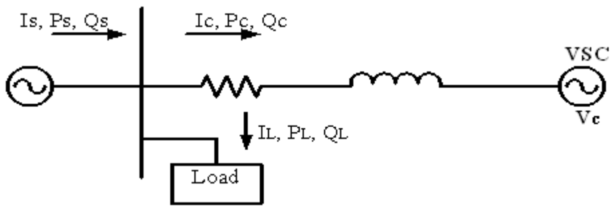

Figure 2. Single line diagram of STATCOM

Where

V_S : RMS line to neutral AC grid voltage

V_C : RMS line to neutral STATCOM fundamental voltage

Is : RMS source fundamental current

I_L : RMS load fundamental current

I_C : RMS STATCOM fundamental Current

Q_S : Source reactive power

Q_L : Load reactive power

Q_C : STATCOM reactive power

R :Y- equivalent of total loss resistance including coupling transformer losses, input filter losses and converter losses

X :Y-equivalent of total reactance including source reactance, leakage reactance of coupling transformer, and input filter reactance.

Fig.3 represents the phasor diagram for lossy systems.

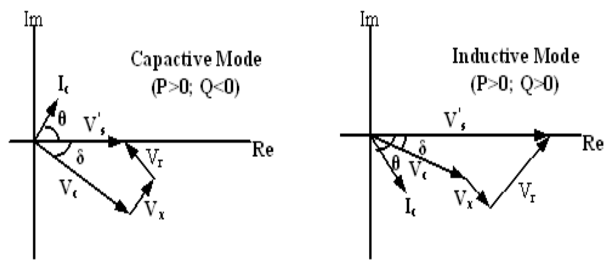

Figure 3. Phasor diagram for lossy system (not to scale)

Equations (1) & (2) are obtained by resolving V_R and V_X along the real and imaginary axis.

$$V_s' - V_c \cos\delta = (R\cos\theta + X\sin\theta)I_c \quad (1)$$

$$V_c \sin\delta = (X\cos\theta - R\sin\theta)I_c \quad (2)$$

Active and reactive power consumed by the STATCOM from the supply can be expressed as in (3) and (4) according to power sink convention.

$$P_c = V_s' I_c \cos\theta \quad (3)$$

$$Q_c = V_s' I_c \sin\theta \quad (4)$$

Active and reactive power inputs to the STATCOM can also be expressed in terms of line-to-neutral voltages Vs' and VC, circuit parameters R & X and angles θ and δ as given in (5) and (6).

$$P_c = \frac{V_s'}{X}\left[\frac{RV_s'\sin\theta + XV_c\sin\theta\sin\delta - RV_c\sin\theta\cos\delta + RV_c\cos\theta\sin\delta}{R\cos\theta + X\sin\theta}\right] \quad (5)$$

$$Qc = V_s' \frac{V_s' - V_c\cos\delta}{R\cos\theta + x\sin\theta}\sin\theta \quad (6)$$

(5) and (6) can be simplified respectively to (7) and (8),by assuming that R<<X.

$$Pc \cong \frac{V_s' Vc}{X}\sin\delta \quad (7)$$

$$Qc \cong V_s' \frac{V_s' - Vc\cos\delta}{X} \quad (8)$$

Modulation index (m) can be defined as in (9) for SPWM or SHEM.

$$V_{CD} = m\frac{V_{dc}}{2} \quad (9)$$

where, V_{dc} is the mean dc link voltage and VCD is the peak value of the fundamental component of line to neutral STATCOM voltage.

Therefore Pc and Qc can be expressed in terms of modulation index and dc link voltage as given in (10), and (11) respectively.

$$P_c \cong \frac{0.35 V_s'}{X} mV_{dc} \sin\delta \quad (10)$$

$$Q_c \cong \frac{V_s'}{X}(V_s' - 0.35\, mV_{dc}\cos\delta) \quad (11)$$

If STATCOM were a lossless system, Pc, and hence ä would be zero, while supplying constant Q_c to constant Vs' in the steady state. However, for a practical VSC STATCOM, system losses can be supplied by keeping ä at a very small value, while delivering or absorbing constant Qc in the steady state. Therefore, cosä can be approximated to unity for STATCOM operating at constant reactive power.

In view of the above findings and (11), reactive power can be controlled by one of the following techniques:

(i) varying modulation index m, while keeping DC link voltage V_d constant

(ii) varying V_d, while keeping m constant

(iii) varying both m and V_d

The highly mathematical PWM method has two base terms modulation index and modulation ratio. Modulation index determines the output voltage fundamental component, while the modulation ratio determines the incident (location) of harmonic in the spectra.

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B. Selective Harmonc Elimination

Harmonic content of STATCOM line current i_c in Fig.1 should comply with IEEE Std. 519-1992. This can be achieved by applying a proper PWM technique such as SHEM. In this research work, since fixed dc link voltage and variable modulation index has been chosen, harmonic content of line current and load voltage will be minimized by SHEM technique. At the expense of coupled active and reactive power control, and relatively slower transient response, it is advantageous to apply SHEM to VSC topology. A general 2 level 3 leg VSI is shown in Fig. 4.

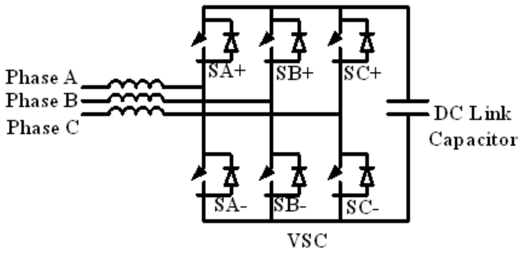

Figure 4. A general 2-level 3-Leg voltage source converter

The switching pattern of IGBT switches are defined on the basis of the modulation index (m) and the phase shift (á). The two patterns are then given to the VSC circuit via PWM module which produces switching pattern of IGBTs to produce a corresponding or desired 3 phase voltage waveform for STATCOM application.

The SHEM allows optimized PWM pattern, its implementation is much easy. The switching frequency of power semiconductor, f_s is directly related to the number of harmonics to be eliminated [19], as given below.

$$f_s = (2N+1) f_1 \qquad (12)$$

where f_1 is the grid frequency and hence the fundamental frequency.

The i_c waveforms are found by Vc waveform arising from SHEM, by simulating this circuit in MATLAB. This is because in application where STATCOM, is going to be utilized as VAr compensator, or terminal voltage regulator, point of common coupling (PCC) should be taken as common connection of STATCOM. Therefore, total harmonic distortion (THD) values of STATCOM line current and individual magnitude of harmonic components at PCC are of the designer's direct interest, and should comply with the IEEE std. 519-1992.

III.Neuro Controller

Neuro-controllers may originate from various sources. Neural networks may be trained to mimic the control action of existing VSC controllers, thereby distributing the inverter functionality over several neurons. Neuro-controllers are also developed utilizing evolutionary reinforcement learning techniques [20]. Neural networks are beneficial to an adaptive scheme, such as generalization and graceful degradation. Neural network controllers are collections of neurons, with each neuron specifying the weights from the input layer (process states) to output layer (control actions). Neuro-controller parameters are the neural network weights.

A. Block Representation of Neuro Controller

ANC maintains a population of possible neuro-controller solutions that serve as reinforcement learning evaluations, similar to EVOP experiments [21]. The neuro-controller is evaluated individually over a number of sensor sample periods while interacting with a dynamic process as in Fig. 5.

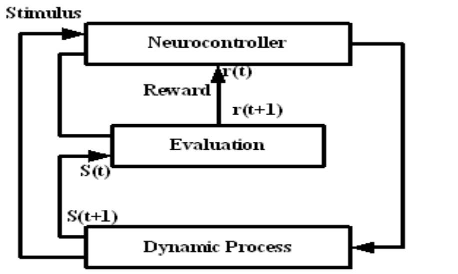

Figure 5. The proposed adaptive controller

Initially, the process may be at an arbitrary operating point (state, st). The neuro-controller observes the current process operating point at sample, t, and selects a control action, at. The control action changes the operating point to st+1. A reward, rt, is assigned based on the economic value of this new operating point. The objective is to maximize the total reward over a series of control actions, while maintaining a specified control response. An optimization algorithm adapts the neural network weights based the reward feedback from each evaluations. The above controller can also be represented as shown in Fig. 6 while maintaining the above explained generality.

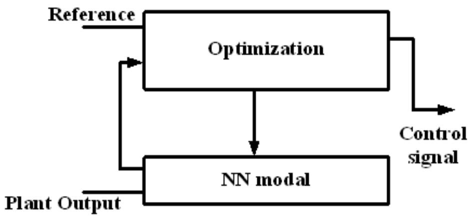

Figure 6. The adaptive neurcontroller

The neural network model and the simulation block of above said ANC is shown in Fig. 7.

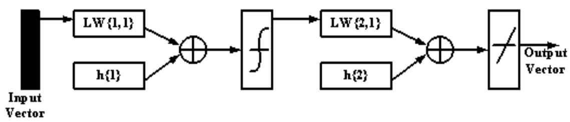

Figure 7. ANC network representation

The shown network can be trained for a given set of plant parameter data-base. The training will result in optimum set of weights and bias, for a predefined number of neurons, selected for achieving the selected/ or the defined performance and the control criterion.

IV.Validation and Result Discussion

The switching test circuitry used is shown in Fig. 4. The analysis is comparative in nature as the other circuitry is

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nearly the same except that the firing pulses for the VSC are now generated by the adaptive neuro controller, which forms the part of the feedback circuit that has its reference from the conventional VSC circuitry (ref. fig. 5) and the 3 phase voltage output is fed back to the ANN controller and then the neuro controller generates the firing pulses for the VSC (ref. fig 6).

The comparison is made between the current and voltage outputs at the load and at the PCC. The simulations are carried in MatLab and the waveforms obtained are shown below.

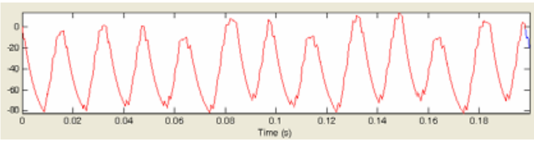


Figure 8.RMS fundamental load current

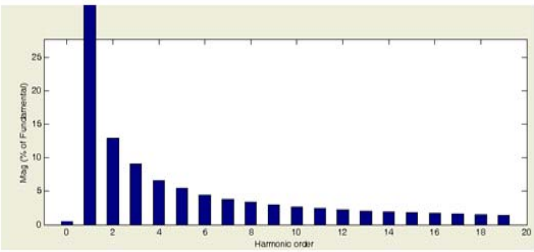
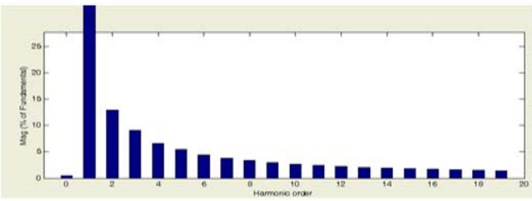


Figure 9. RMS load current harmonics as a percentage of fundamental components for I_L.



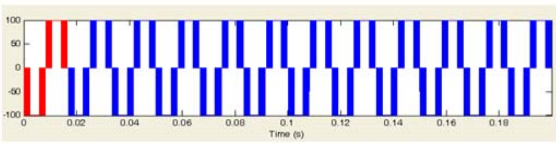


Figure 10. RMS line to neutral STATCOM fundamental voltage

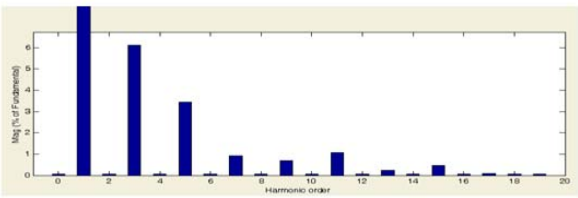


Figure 11. RMS VSC voltage harmonics as a percentage of fundamental component of V_c

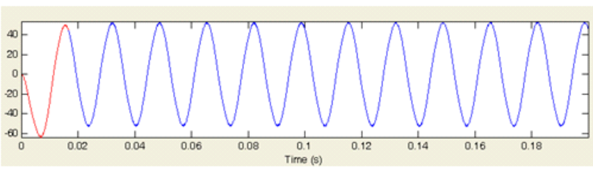


Figure 12. RMS fundamental load current of ANN based VSC.

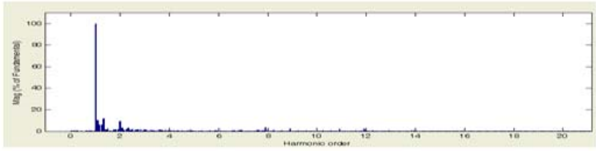


Figure 13. RMS load current harmonics as a percentage of fundamental components for I_L of ANN based VSC.

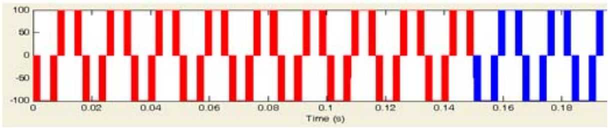


Figure 14. RMS line to neutral STATCOM fundamental voltage of ANN based VSC

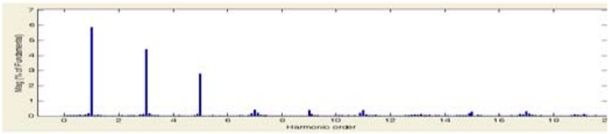


Figure 15. RMS VSC voltage harmonics as a percentage of fundamental components of V_c of ANN based VSC.

From the simulation results, it is found that the neural network based VSC performs in a better way. In order to make it more clear, the results for the odd harmonics current components are given in Table 1.

TABLE I.
HARMONIC DISTORTION IN LINE CURRENT OF VSC BASED STATCOM AT THE POINT OF COMMON COUPLING

Harmonic number n	VSC (in %)	ANN based VSC (in %)	Limits recommended by IEEE std. 519-1992 (in %)	
			$20 < I_{sc}/I_L < 50$	$I_{sc}/I_L < 20$
3	9.09	1.56	7	4
5	5.41	0.35	7	4
7	3.83	0.23	7	4
11	2.44	0.24	3.5	2
17	1.58	0.08	2.5	1.5
19	1.41	0.06	2.5	1.5

If individual harmonic magnitude and also their THD values are compared with the limit given in IEEE Std. 519-1992, it can be concluded that SHEM technique is very successful in approximating the line current waveform of STATCOM to a pure sine wave. The same can be extended to the voltage waveforms also.

V. Conclusion

The paper describes the design, implementation, and performance of an adaptive neural controller of a VSC based STATCOM. Voltage regulation is achieved by optimizing the modulation index and VSC harmonics are eliminated by

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SHEM technique. The proposed system complies with the IEEE std. 519-1992 The selective harmonic elimination technique applied to voltage source converter based static synchronous compensator leads to reduction in switching frequency, the same method can also be used for reactive power control with slight modification in design and implementation.

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